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16. ABSTRACT

Previously reported thresholds for UV-B dose and dose-rate were determined under artificial light regimes using more than an order of magnitude less visible light than found naturally. Near-UV and/or visible light is needed for photoreactivation and the accuracy of earlier findings may have been influenced by less than maximum photorepair in the laboratory. Experiments with shrimp larvae and adult euphausiids, comparing survival at various UV-B doses and dose-rates combined with different levels of near-UV and visible irradiance, suggest that photorepair reaches maximum levels at relatively low visible light intensities.

Previously reported tolerance limits for shrimp larvae and adult euphausiids were confirmed (in particular, the relationship between dose/dose-rate safe and lethal limits in shrimp). Also, the earlier experimental design did not appear to have affected these limits since additional near-UV and visible light did not substantially alter the results.

In experiments using a 44-l plastic cylinder (140-cm water depth), adult euphausiids successfully avoided moderate UV-B combined with visible light, but were attracted to and ultimately killed by higher levels of UV-B irradiance would become an important factor in a new solar spectral distribution caused by ozone depletion.

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JOURNAL ARTICLE

UV damage and photoreactivation potentials of larval shrimp, *Pandalus platyceros*, and adult euphausiids, *Thysanoessa raschii* *

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Summary. Previously reported thresholds for UV-B dose and dose-rate were determined under artificial light regimes using more than an order of magnitude less visible light than found naturally. Near-UV and/or visible light is needed for photoreactivation, and the accuracy of earlier findings may have been influenced by less than maximum photorepair in the laboratory. Experiments with shrimp larvae and adult euphausiids, comparing survival at various UV-B doses and dose-rates combined with different levels of near-UV and visible irradiance, suggest that photorepair occurs in these organisms. Further, this apparent photorepair reaches maximum levels at relatively low visible light intensities.

Previously reported tolerance limits for shrimp larvae and adult euphausiids were confirmed (in particular, the relationship between dose/dose-rate safe and lethal limits in shrimp). Also, the earlier experimental design did not appear to have affected these limits since additional near-UV and visible light did not substantially alter the results.

In experiments using a 44-l plastic cylinder (140-cm water depth), adult euphausiids successfully avoided moderate UV-B combined with visible light, but were attracted to and ultimately killed by higher levels of UV-B combined with low visible light. The apparent inability of euphausiids to directly detect harmful levels of UV-B irradiance would become an important factor in a new solar spectral distribution caused by ozone depletion.

The potential impacts of enhanced solar UV-B irradiation on natural marine ecosystems cannot yet be predicted. However, several physiological processes in near-surface zooplankton have been shown to be adversely affected under artificial UV-B sources in the laboratory. A general criticism of studies using fluorescent lamps to simulate solar UV-B irradiation (285–315 nm) is that the UV-A and visible components (315–390 nm and 390–780 nm) are often more than an order of magnitude less intense than in sunlight (NAS 1979; NRC 1982). This substantial difference in intensity could mask a number of synergistic or antagonistic effects normally attributed to the relatively higher intensities of the long wave solar spectrum. Among the most widely recognized beneficial effects of the near-UV and visible light of the sun is the photoreactivation mechanism for UV-B damaged DNA. This enzymatic "photorepair" system occurs in a wide variety of organisms (Rupert 1964; Jagger 1967; Cook 1970; Murphy 1975; Nachtwey 1975; Rupert 1975; Sutherland 1975; Siebeck 1978; Jokiel and York 1982). While there exists some uncertainty as to the various action spectra for photoreactivation, there is little doubt regarding its importance in repairing UV-B induced chemical lesions in DNA (Jagger 1967; Nachtwey 1975; Murphy 1975; Siebeck 1978). Nevertheless, there is little information regarding the rates and limits of repair abilities. Tolerance of increased UV-B through photoreactivation is limited and probably varies with species. Differing sensitivities may result from different capacities of organisms to acclimate to or repair damage from UV-B, or from differences in the attenuation of UV-B before it is absorbed by the critical cellular components.

Previously reported dose/dose-rate responses for larval shrimp (*Pandalus* spp.) and adult euphausiids (*Thysanoessa raschii*) were determined using artificial light sources to approximate solar UV-B (Damkaer et al. 1980, 1981). The results of these studies suggest that in assessing the effects of UV-B irradiation, one must consider both dose and dose-rate, since for each of these factors there appear to be thresholds below which no harmful effects are observed. Given the ubiquity and established effectiveness of photoreactivation, and the unnaturally low levels of photoreactivating light used in these experiments, the validity of these thresholds and conclusions drawn from them might be questioned.

Among Crustacea, photoreactivation enzyme activity has been detected in tissues of the land crab, *Gecarcinus lateralis*, (Cook and McGrath 1967); brine shrimp nauplii, *Artemia salina*; and the lobster, *Homarus americanus*, (Rupert 1975). There are apparent differences between spectral responses of photoreactivating enzyme from various species, but, in general, the action spectra lie in the range of near-UV and blue light, 315–500 nm (Cook 1970; Murphy 1975; NAS 1979). UV-A damages cells, but with very low efficiency; its primary effect is to modify the action of UV-B through photoreactivation (NRC 1982). The spectral distributions including these wavelengths for incident solar radiation at Manchester, Washington, and a typical experimental setup using fluorescent lamps, are shown in Fig. 1. Total DNA-weighted UV-B irradiance can be approximately the same in each case (0.004 Wm^{-2} [DNA]), yet the total near-

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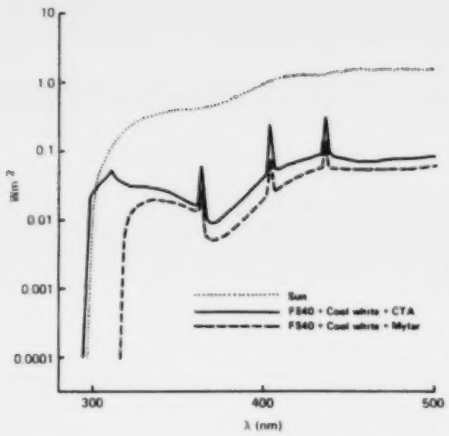

	Irradiance (Wm^{-2})			
	DNA	Unweighted		
	UV–B 285 to 315 nm	UV–A 316 to 390 nm	PR Visible 391 to 500 nm	Total PR light 316 to 500 nm
Sun	0.0044	29.8	115.9	145.7
FS40 + Cool white + CTA	0.0038	1.8	8.4	10.2
FS40 + Cool white + Mylar	—	1.1	6.1	7.2

Fig. 1. Spectral irradiance of solar and artificial light sources, 285–500 nm, measured spectroradiometrically. Total UV-B (DNA weighted) irradiance and irradiance of probable photoreactivating (PR) light bands are indicated for each source

UV and blue components of the artificial sources are only 7% of solar irradiance in this same range. In sunlight, then, there is a great potential for concurrent photorepair of damage due to UV-B.

There is also the possibility that with or without an effective photoreactivation system, some organisms can physically sense dangerous levels of UV-B either directly or indirectly and avoid it (Damkaer and Dey 1982). For this additional reason, it would be important to consider the relative intensities of various wavelength bands when evaluating experimental radiation and incident, or future incident, solar radiation.

The primary objectives of this study were 1) to provide evidence of the photoreactivation potentials in near-surface shrimp larvae and adult euphausiids, 2) to reevaluate dose and dose-rate thresholds for shrimp larvae and adult euphausiids in view of their possible photoreactivation potentials, and 3) to examine vertical-positioning responses of euphausiids as an additional or complementary defense against harmful UV-B and to assess the possible effects of this behavior under conditions of increased incident solar UV-B radiation.

Materials and methods

Experiments were conducted at the National Marine Fisheries Service/NOAA Marine Experimental Station on Puget Sound at Clam Bay, Manchester, Washington. Seawater was pumped directly from the bay, sand filtered, and partially sterilized with germicidal UV. Water taoles, artificial light sources and filters, measurement techniques and equipment for spectral irradiance, and the acquisition, identification, and culture of test organisms are described by Damkaer et al. (1980). Calculations for biologically effective UV-B irradiance (285–315 nm) employed the analytical representation of Green and Miller (1975) which is based on the DNA action spectrum of Setlow (1974). To verify previously reported UV-B dose/dose-rate safe and lethal zones for shrimp larvae (Damkaer et al. 1981), paired sets (5 replicates, of 10 larvae each, per set) of newly hatched specimens were irradiated with moderate to extremely high UV-B dose-rates for different periods of exposure. At the three dose-rates selected (0.0055, 0.0085, and 0.024 Wm^{-2} [DNA]), one set of larvae in each pair was given a safe total dose and the other set a lethal total dose. Periods of exposure ranged from less than 1 h to 5 h depending on dose-rate. Once the intended total dose had been administered, there was no subsequent irradiation other than low-level daytime laboratory light. In addition, one set of 50 shrimp larvae was exposed daily to what past work had suggested may be a safe dose-rate (0.0014 Wm^{-2} [DNA]). Cool-white fluorescent lamp and FS-40 sunlamp combinations filtered with cellulose triacetate (CTA) supplied UV-B and longer wavelength irradiance. A control group of 50 larvae received irradiance 3 hd^{-1} from the same combination of lamps filtered with Mylar®[1] to exclude UV-B and shorter wavelengths.

A second, similar experiment was conducted with shrimp larvae with the following major addition: subsequent to receiving the specified total dose, each group of larvae received near-UV and visible irradiation equivalent to that given the controls; i.e., 3 hd^{-1} of cool-white and FS-40 lamps filtered with Mylar.

Adult euphausiids, *Thysanoessa raschii*, captured at midday from Clam Bay surface swarms were divided into six groups (5 replicates, of 10 larvae each, per group) and placed in the water table. Four of these groups were irradiated with UV-B at dose-rates of 0.0028–0.0030 Wm^{-2} [DNA], which were slightly below the postulated threshold of 0.0033 Wm^{-2} [DNA] (Damkaer et al. 1981). Of the four treatments, one was administered for 3 hd^{-1} with one FS-40 sunlamp and one cool-white lamp, both filtered with CTA; a second group received the same UV-B irradiance as the first but with an additional 3 hd^{-1} of only near-UV and visible light (FS-40 sunlamp and cool-white lamp, Mylar-filtered); the third group was irradiated with two FS-40 sunlamps filtered with CTA (no cool-white) for 3 hd^{-1}; and the fourth treatment was similar to the third but with an additional 3 hd^{-1} of only near-UV and visible radiation. A fifth group of 50 euphausiids received the much higher UV-B dose-rate of 0.0041 Wm^{-2} [DNA] for 3 hd^{-1} from an FS-40 sunlamp and cool-white lamp filtered with CTA, with an additional 3 hd^{-1} of only near-UV and visible light. The control group received 3 hd^{-1} of only near-UV and visible light (FS-40 sunlamp and cool-white lamp, Mylar-filtered).

To examine behavioral responses to potentially damag-

1 Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA

ing UV-B combined with different levels of near-UV and visible light, freshly collected adult euphausiids were placed in a clear plastic cylinder, 165-cm high, 20-cm diameter, filled with seawater to a depth of 140 cm (volume = 44 liter). The cylinder was in a darkened room where the only source of light was the lamps suspended above the open top of the cylinder. The cylinder was marked at water depths of 30, 60, and 90 cm, and the vertical distributions of the 25 test organisms in each treatment were recorded before turning on the lights and at 5, 30, 60, 120, and 180 min after exposure began each day. Seawater in the cylinder was slowly drained and replenished daily. Aeration and food (*Artemia salina*) were supplied between periods of illumination. In one treatment, the euphausiids received a moderate dose-rate of UV-B (0.0047 Wm^{-2} [DNA]) and longer wave irradiance for 3 hd^{-1} from an FS-40 sunlamp and cool-white lamp combination filtered with CTA. In a second case, the irradiance of two FS-40 sunlamps filtered with CTA provided a high UV-B dose-rate (0.012 Wm^{-2} [DNA]) and low visible irradiance for 3 hd^{-1}. Subsequent to each of these experiments, fresh specimens (controls) were exposed to identical lamp configurations but with the addition of Mylar filters.

Results

Earlier experiments with shrimp larvae demonstrated the necessity of considering thresholds for *both* the dose-rate and the total dose of UV-B (Damkaer et al. 1981). It was concluded that at dose-rates below about 0.002 Wm^{-2} [DNA], shrimp larvae can tolerate and repair UV damage, even for the entire 2 to 3 weeks of near-surface occurrence. However, above that dose-rate threshold, the shrimp larvae die if the total dose exceeds about 85 Jm^{-2} [DNA]. New observations on the effects of high dose-rates for short times, that is, for total doses just above and just below the total-dose threshold value, indicate low survival for all groups tested compared with the controls (Fig. 2). The three groups of shrimp larvae receiving total doses below 85 Jm^{-2} [DNA] died at a slower rate than those irradiated with the same high dose-rates but with higher total doses. These observations suggest that the total dose threshold, at least at these high dose-rates, is lower than had previously been estimated. However, the intensities and times (continuous 40 min to 5 h only) of irradiation in this experiment were clear departures from earlier experiments used to determine the total dose threshold.

To reevaluate the responses of shrimp larvae receiving near-threshold doses at high dose-rates, and at the same time to determine photorepair potentials, a second experiment was conducted. Paired sets of newly hatched shrimp larvae were given the same combinations of UV-B dose-rates and total doses as in the first experiment, but in each case this was followed by 3 hd^{-1} of near-UV and visible irradiation (equivalent to that given the controls) without subsequent UV-B irradiation. This approach more closely paralleled past experiments where organisms received 3 hd^{-1} of near-UV and visible irradiation together with daily UV-B irradiation. In the second experiment, survival dramatically increased in the three treatments receiving a UV-B total dose of less than 85 Jm^{-2} [DNA] at high dose-rates (Fig. 3). The three sets of larvae receiving a UV-B total dose greater than 85 Jm^{-2} [DNA] at the same high dose-rates again showed poor survival. The results from

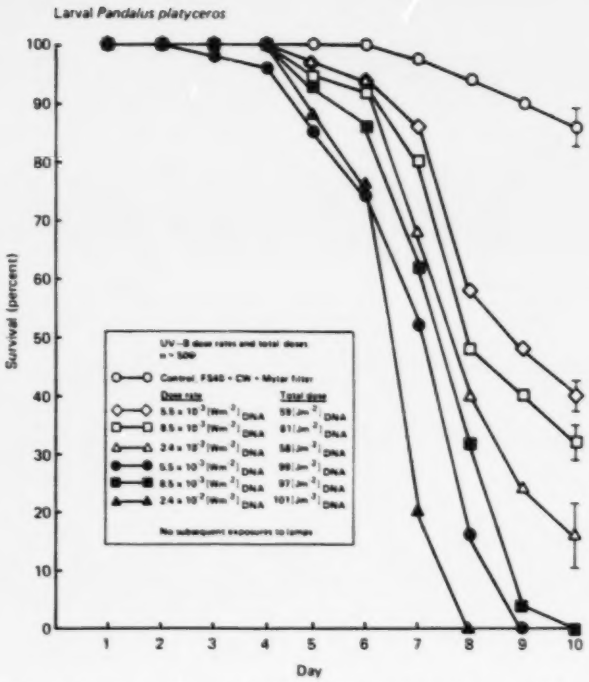

Fig. 2. Percent survival from birth through 10 days of larval *Pandalus platyceros*, at seven levels of UV-B radiation *without* subsequent photoreactivating light. Temperature 9.3–9.8° C. Capped vertical lines represent 95% confidence limits of five replicates

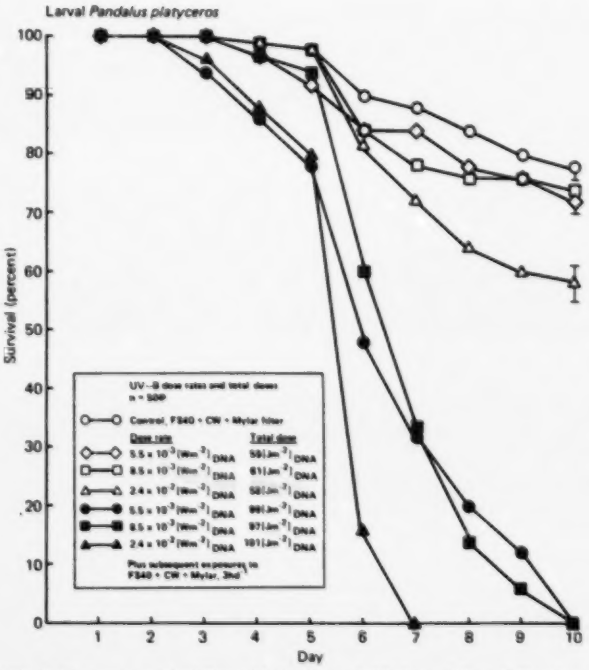

Fig. 3. Percent survival from birth through 10 days of larval *Pandalus platyceros*, at seven levels of UV-B radiation *with* subsequent photoreactivating light. Temperature 9.6–9.9° C. Capped vertical lines represent 95% confidence limits of five replicates

this second experiment have been incorporated into earlier data (Fig. 4) upon which the UV-B dose/dose-rate thresholds are based (Damkaer et al. 1981). It is clear that the subsequent near-UV and visible light treatments increased survival when the UV-B dose/dose-rate regimes were near and below threshold levels, but the treatments did not alter survival when exposures were above thresholds.

Also added to Fig. 4 is the result obtained from irradiating a set of 50 shrimp larvae at the safe UV-B dose-rate of 0.0014 Wm^{-2} [DNA] for 3 hd^{-1}. This UV-B irradiation was in addition to near-UV and visible light. About 80% of the larvae survived for 25 days (total dose about 400 Jm^{-2} [DNA]), and 66% survived for 32 days at which time the experiment was terminated. The duration of near-surface occurrence of these larvae is believed to be only 2 to 3 weeks.

Previously determined dose/dose-rate UV-B threshold levels for adult euphausiids are 215 Jm^{-2} [DNA] and

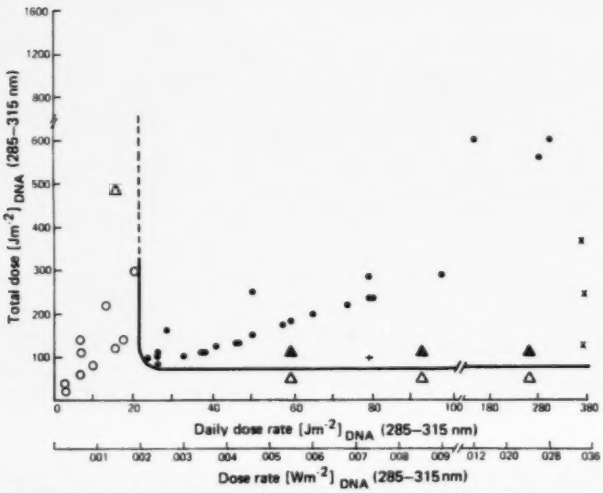

Fig. 4. Lethal effects on shrimp larvae for various combinations of UV-B dose-rate and total dose. Open symbols indicate maximum observed combinations for survival; other symbols indicate minimum observed combinations for mortality (after Damkaer et al. 1981). The seven triangles are new observations, to which the *daily* dose-rate scale does not apply

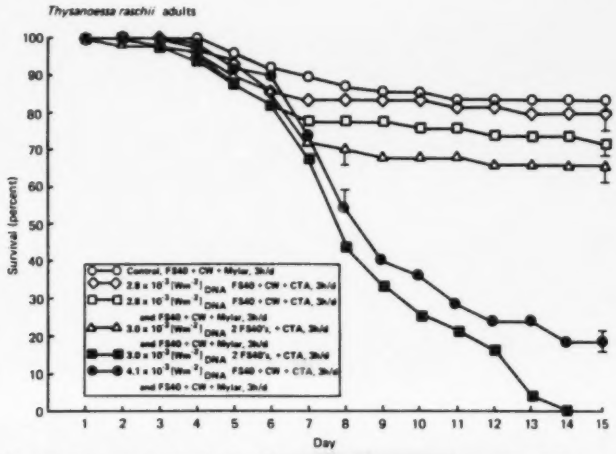

Fig. 5. Percent survival of wild-caught *Thysanoessa raschii* adults over 15 days, at four levels of UV-B radiation with and without subsequent photoreactivating light. Temperature 10.0–10.6° C. Capped vertical lines represent 95% confidence limits of five replicates

Table 1. Survival of adult euphausiids exposed to UV-B, with or without subsequent photoreactivating (PR) light. Symbols as in Fig. 5

Treatment	Daily irradiance dose				
	DNA weighted (Jm^{-2})	Unweighted irradiance dose (kJm^{-2})			
	UV-B 285–315 nm	UV-A 316–390 nm	PR visible 391–500 nm	Total PR light 316–500 nm	% Survival (15 days)
Control					
FS 40 + CW + Mylar, 3 hd^{-1} (○)	–	11.9	65.9	77.8 (at 7.2 Wm^{-2})	84
FS 40 + CW + CTA, 3 hd^{-1} (◇)	30 (at 0.0028 Wm^{-2})	16.2	82.1	98.3 (at 9.1 Wm^{-2})	80
FS 40 + CW + CTA, 3 hd^{-1} FS 40 + CW + Mylar, 3 hd^{-1} (□)	30 (at 0.0028 Wm^{-2})	28.1	148.0	176.1 (at 16.0 Wm^{-2})	72
2 FS 40's + CTA, 3 hd^{-1} FS 40 + CW + Mylar, 3 hd^{-1} (△)	33 (at 0.0030 Wm^{-2})	24.3	77.9	102.2 (at 9.5 Wm^{-2})	66
2 FS 40's + CTA, 3 hd^{-1} (■)	33 (at 0.0030 Wm^{-2})	12.4	12.0	24.4 (at 2.3 Wm^{-2})	0
FS 40 + CW + CTA, 3 hd^{-1} FS 40 + CW + Mylar, 3 hd^{-1} (●)	44 (at 0.0041 Wm^{-2})	32.4	166.3	198.7 (at 18.4 Wm^{-2})	18

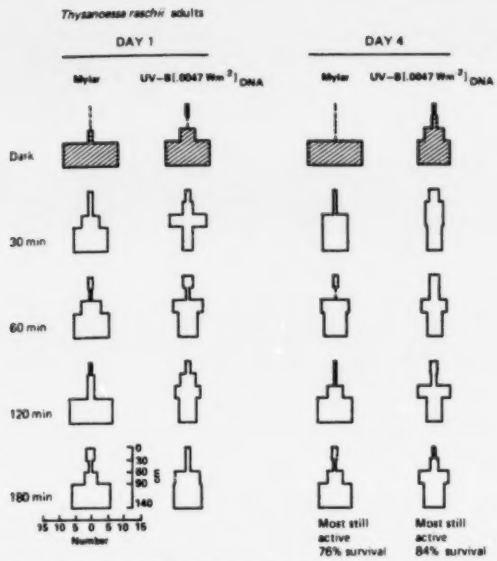

Fig. 6. Vertical distributions of *Thysanoessa raschii* in a plastic cylinder (water depth 140 cm), during 3-h exposures with moderate visible radiation with and without moderate UV-B radiation

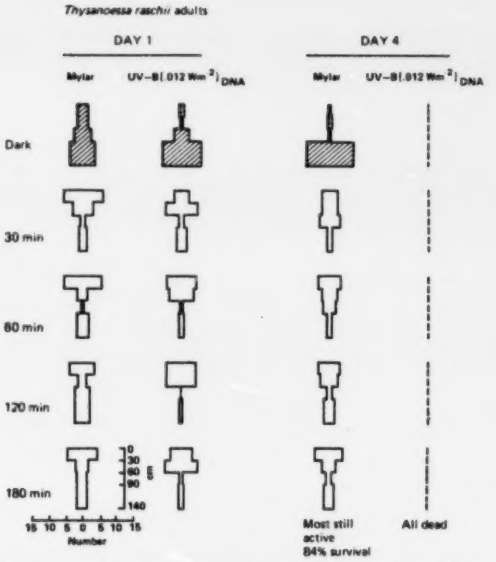

Fig. 7. Vertical distributions of *Thysanoessa raschii* in a plastic cylinder (water depth 140 cm), during 3-h exposures with low visible radiation with and without high UV-B radiation

0.0033 Wm^{-2} [DNA] (Damkaer et al. 1981). Of four groups irradiated at slightly below the dose-rate threshold, only the three groups receiving supplemental near-UV and visible irradiation, either concurrently or subsequently, experienced good survival (Fig. 5). The fourth group, which received no cool-white light and had no survivors after 14 days, received the same UV-B dose/dose-rate with the same lamp and filter combinations as the group with 66% survival after 15 days. Over the course of the experiment, however, the group which did not survive received less than 25% of the photoreactivating light (316–500 nm) available to the surviving comparison group (Table 1). The light treatments for the other two groups, irradiated at just below the UV-B dose-rate threshold level, also differed in respect to the levels of photoreactivating light. One group was irradiated with UV in conjunction with visible light at levels consistent with past experiments. The comparison group received this same irradiation but with 3 hd^{-1} subsequent, additional near-UV and visible light. Therefore, while each of these two groups received the same UV-B irradiation, the latter group received almost 80% more photoreactivating light (Table 1). Both groups survived well, but further positive effects of the additional photoreactivating light were not apparent (Fig. 5). Similarly, the survival of adult euphausiids exposed to UV-B beyond the dose-rate threshold (i.e., to 0.0041 Wm^{-2} [DNA]) was not much improved over previous observations by a doubling of the daily dose of photoreactivating light (Table 1 and Fig. 5).

When adult euphausiids were placed in a deep cylinder and subjected to above-threshold levels of UV-B irradiation (i.e., to 0.0047 Wm^{-2} [DNA]) combined with the visible irradiation (16.6 Wm^{-2}, 391–800 nm) from a cool-white lamp, they appeared to avoid the full effects of the light by generally positioning themselves in the lower two-thirds of the cylinder (Fig. 6). After 4 days of 3 hd^{-1} treatments, during which this response continued, survival was 84%. When the experiment was conducted with a Mylar filter to attenuate the UV-B, the vertical positioning response and survival of an equivalent group of euphausiids were similar. A second set of experiments was conducted without the visible irradiation of the cool-white lamp (Fig. 7). All irradiance was provided by two FS-40 sunlamps, filtered with CTA in one case and with Mylar in the other. Through the CTA filter, UV-B irradiance was 0.012 Wm^{-2} [DNA], which was over three times the threshold dose-rate and over twice the UV-B irradiance in the first set of vertical positioning experiments. However, without the cool-white lamp, total visible irradiation (2.8 Wm^{-2}, 391–800 nm) was reduced by about six times. Both with high UV-B irradiance and without UV-B, the phototaxis of the euphausiids was much more strongly positive (Fig. 7) than when the UV-B irradiance had been lower and the visible irradiance much greater (Fig. 6). By Day 4, all specimens in the higher UV-B treatment were dead, while 84% of those in the Mylar-filtered treatment survived, with many continuing to move toward and remain near the surface during light exposures.

Discussion

The photochemistry and photobiology of UV-B induced damage, particularly nucleic acid disruption, as well as the several molecular repair mechanisms which are consistently found in plants and animals, have been reviewed by Caldwell and Nachtwey (1975). Among the repair mechanisms, the quantitative capacity of the dark repair systems is quite different from those systems which require light. Under our experimental conditions, it is presumed that the dark repair mechanisms could function freely. While dark repair systems appear to offset a very high proportion of the damage caused by relatively *low* doses of irradiation, it is often found that photorepair mechanisms fix a certain constant percentage of UV-B induced damage over a fairly wide

UV-B dose range (Murphy 1975). Consequently, the restorative effects of photoreactivation may be regarded as particularly critical in situations where organisms are subjected to UV-B irradiation near and above tolerance limits. The dramatic sensitivity of both shrimp larvae and adult euphausiids when deprived of photoreactivating light clearly demonstrates the relative importance of photorepair under UV stress.

In addition to suggesting photoreactivation in shrimp larvae and adult euphausiids, the results of these experiments supported earlier reported threshold UV-B levels. In the first experiment with shrimp larvae, the dose-rates were well above the threshold value of 0.002 Wm^{-2} [DNA], yet in three of the treatments the *total dose* was presumed to be nonlethal. However, the lack of subsequent photoreactivating light in this experiment had perhaps the equivalent effect of an increase in the total dose of damaging UV-B under more-natural lighting. Just below threshold levels, either an increased UV-B dose or a lack of photorepair possibilities could create lethal conditions. In such a case, none of the treatments would have good survival (Fig. 2).

With the additional near-UV and visible irradiation in the second shrimp experiment, only those treatments below the estimated threshold for total dose showed significant increase in survival (Figs. 3–4). Despite the subsequent photoreactivating light, the larvae that received a total dose above the threshold level died at least at the same rate as before. The experiments to date suggest that the previously derived dose/dose-rate thresholds are not altered with additional photoreactivating light. However, a lack of photoreactivating light, which normally would be concurrent with solar UV-B, would depress threshold levels.

For shrimp larvae, the existence of a dose-rate threshold below which repair mechanisms could keep pace with the damaging effects of UV-B, as well as the proposed threshold, was supported by the survival of larvae for more than 4 weeks (experiment intentionally terminated) at a dose-rate of 0.0014 Wm^{-2} [DNA] for 3 hd^{-1} (Fig. 4). Even though this dose-rate is near the natural mean surface solar UV-B dose-rate, the total dose (485 Jm^{-2} [DNA]) was far in excess of that which these larvae are likely to receive during their period in the near-surface of Puget Sound (Damkaer et al. 1981).

Photoreactivation in adult euphausiids also appears to operate effectively at relatively low levels of visible irradiance. Previously estimated UV-B thresholds were supported by new experiments. The earlier experimental design included low levels of near-UV and visible irradiation along with the UV-B irradiation. This appears to have been adequate for the determination of realistic thresholds. Probably the omission of even this low level of photoreactivating light would have significantly lowered the UV-B thresholds. On the other hand, considerably more visible light would not have greatly increased the thresholds.

The reported experiments still have not approached the intensity or dose of local solar photoreactivating light. What we have observed at UV-B exposures below threshold levels is that maximum photorepair potential is reached between the low intensities of 2–9 Wm^{-2} photoreactivating light (Fig. 8). There must also be a critical photoreactivating light *dose*, which for euphausiids is observed to be at about 80 $kJm^{-2}d^{-1}$, available over about 8 days for initial effect. Nearly doubling the dose-rate and dose of photoreactivating light did not increase the survial of euphausiids (Fig. 8). It is doubtful that photorepair, and therefore related survival, would be greater at solar intensities. A similar relationship has been reported between survival in UV-damaged anchovy larvae and intensities of photoreactivating light (Kaupp and Hunter 1981). Above the UV-B threshold level (where normalized survival after 4 days was less than 80%), subsequent photoreactivating light had a small effect on anchovy survival, but the ultimate survival rate may not have been much influenced. Just below the UV-B dose-rate threshold level, apparently about 0.008 Wm^{-2} [modified DNA], subsequent photoreactivating light very significantly increased survival. However, the photorepair mechanisms appeared to be "fully activated" at a photoreactivating light (320–500 nm) intensity of 7 Wm^{-2} and a daily dose of 77.5 kJm^{-2} available over 4 days. At greater intensities, up to intensities equivalent to solar photoreactivating light at Manchester (Fig. 1), Kaupp and Hunter observed no further increase in anchovy survival. There is extraordinarily close agreement between the relatively low dose-rates and doses necessary for apparent maximum photoreactivation in anchovy larvae and euphausiids.

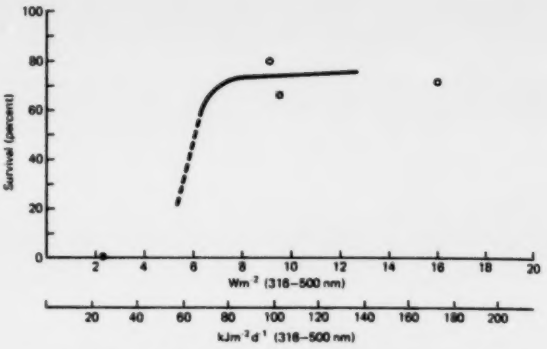

Fig. 8. Survival of euphausiids after 8-days exposure (3 hd^{-1}) of near-threshold UV-B irradiance and subsequent photoreactivating (PR) light (316–500 nm)

The large cylinder experiments with euphausiids pose further questions regarding the effects of strong visible irradiation. Certain shrimp and crab larvae and copepods appear to be attracted to the routine experimental levels of artificial visible irradiation, but have not shown tendencies to avoid harmful levels of UV-B (Damkaer and Dey 1982). Adult euphausiids, on the other hand, seemed to avoid this same level of visible light (with or without UV-B) but were attracted to low levels of visible light with or without extremely high levels of UV-B. This seems inconsistent with the fact that these specimens had just been collected from the surface on a bright, sunny day of visible irradiance many times higher than that which they avoided in the laboratory. Euphausiids may be more sensitive to visible light levels than smaller zooplankters under similar stresses of confinement. Visible light levels high enough for significant photorepair are probably avoided by many species, while some species are likely to be attracted to light inadequate for photorepair. Since reductions in atmospheric ozone would allow disproportionally more incident UV-B than visible irradiation, present responses of some organisms to future solar irradiation may not be optimal.

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